GEOLOGY OF THE MT. TENNYSON AREA, SOUTH OF YETHOLME, N.S.W.

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(Communicated by Associate-Professor T. G. Vallance)

(Plate ix)

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Synopsis

South of Yetholme, N.S.W., stratified rocks of probable Silurian to Devonian age have been metamorphosed to hornblende hornfels facies within the aureoles of the Bathurst Granite and one of its satellites. A western succession of strongly foliated sediments and volcanics is separated by a major structural break from a concentrically folded, unfoliated eastern succession with abundant calcareous sediments. A narrow, north-trending belt of Ordovician to Silurian mafic igneous rocks forms a structurally high basement for the eastern succession.

The geosynclinal Hill End Trough sequence west of Sofala and the geanticlinal stratigraphy at Limekilns, separated by the Wiagdon Thrust (Packham, 1958, 1968) are respectively correlated with the Yetholme western and eastern successions on a petrological and stratigraphic basis.

Introduction

The small township of Yetholme, some 15 miles east of Bathurst (Fig. 1) is situated on a dissected plateau surface about 3,800 feet above sea level, drained by tributaries of the westward flowing Fish River, part of the Macquarie River system. To the south and south-west of Yetholme the elevation of the country sharply falls to the level of the Bathurst Plains (about 2,500 feet) occupied by deeply weathered rocks of the Bathurst Granite.

In the present paper attention is drawn chiefly to the nature and status of the stratified rocks in the Yetholme area. Although most of these rocks occur within the contact aureoles of the Bathurst Granite and an associated body, the Durandal Stock it has been possible to recognize two distinct stratified sequences with fundamentally different sedimentary facies and structural features. A thick north-south trending western sucession of turbidite deposits and volcanics is separated from a relatively thin calcareous eastern succession by a major structural break, the Wiagdon Thrust. The thermal metamorphism of these stratified rocks has produced hornblende hornfels facies mineralogy within the already low-grade regionally metamorphosed succession.

Previous geological investigations in the Yetholme area were concerned mainly with economic potential of molybdenite-bearing skarn rocks at Mt. Tennyson and Andrews (1916) provides a brief account of the early mining history together with a general map of the small mineralized area. In more recent work the western part of the area has been described by Williams (1961) and Mackay (1964) gives a detailed account of the Yetholme granite together with a broad outline of the regional geological setting.

Field locations within this paper refer to the grid reference (GR) on the 1 : 63,360 Bathurst and Oberon military sheets and specimen numbers refer to catalogued rocks and thin sections in the collection of the University of Sydney.

Stratigraphy and Petrology

In establishing the complete succession at Yetholme it is necessary to refer to the stratigraphy and petrology of specific areas to the north. The restricted outcrop between two granitic masses and complete lack of fossils in these contact metamorphic rocks has made correlation on a comparative basis essential.

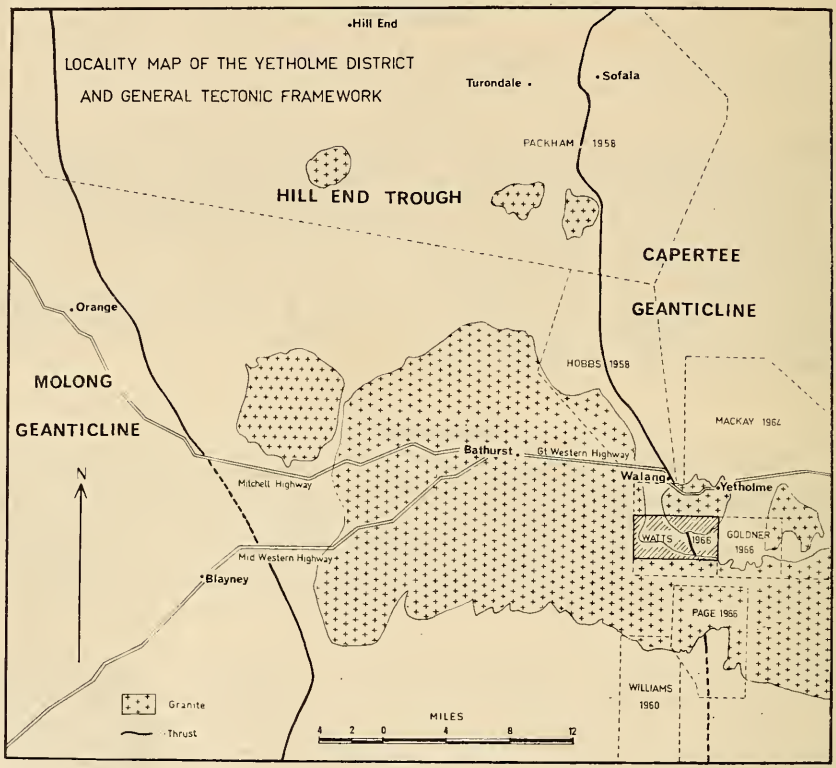


Fig. 1.

West of the Wiagdon Thrust, the stratigraphy which can be recognized in the contact aureole at Yetholme (Fig. 2), is closely related to that defined by Packham (1958) in the Sofala-Turondale area where an essentially conformable geosynclinal sequence ranging from Ordovician to Devonian is exposed particularly along the Turon River. Part of the Limekilns stratigraphy (Packham, 1958) to the east of the Wiagdon Thrust is also considered here (Table 1 provides a comparision of these sequences). Accordingly the stratigraphic nomenclature used is that of Packham (1958, 1966, 1968) in the regional compilation of the Bathurst sheet 1:250,000 geological map.

The Western Succession

Sofala Volcanics

South-west of Yetholme the narrow belt of Sofala Volcanics includes a variety of contact metamorphosed pyroclastic, intrusive and possibly flow rocks with mafic to ultramafic mineralogy. Brecciated rocks which retain igneous textures of both coarse grained strongly porphyritic rock types and fine grained volcanics are common. However textural indication of original igneous character is generally lacking in fine grained strongly foliated rocks

TABLE 1

	Unit	*Sofala-Turondale* Thickness		*Yetholme* Thickness	Western succession	Thickness	Eastern succession
Crudine Group	Waterbeach Formation	1690′	Shaly rocks far more abundant than sandy ones. Tuffaceous rocks absent. Conglomerates absent		Not represented		
	Turondale Formation	2020′	Mainly tuffs, shaly bands prominent towards the top. To the south conglomerate occurs in the upper part. Massive tuffs basally	2500′	Felspathic tuffs and/or greywackes with minor dacitic volcanics interbedded with slates becoming more prominent higher in the succession. Bed of cobble conglomerate is prominent towards the top	1200′	Coarse felspathic tuffs and/or greywackes; calcareous and conglomeratic basally. Overlain and underlain by pelitic lithologies
	Cookman Formation	1500′	Quartz-rich greywackes, occasional grits and conglomerates interbedded with slates. Quartzite-like subgreywacke basally	? 850′	Quartz-rich subgreywacke and greywacke interbedded with slates. Grades upward into more felspathic greywacke		
	Chesleigh Formation	3500′	Massive basal subgreywacke. Interbedded slate and subgreywacke gives way to greywacke and interbedded tuff horizons. Silts and slates in uppermost beds	? 600′	Highly cleaved silts and slates		
	Bell's Creek Volcanics	1500′	Rhyolitic tuffs and lavas. Tuffs basally then rhyolite and finally more tuffs	? 9000′+	Faulting probably invalidates estimate of thickness. Fine-grained quartz-rich foliated rocks. ? Tuffs comprise most of the formation. Minor rhyolites probably occur one-third of the way up the section		
	Tanwarra Shale	250′	The junction with the Sofala Volcanics is obscured by structural disturbance of the Wiagdon Thrust. Basal conglomerate contains limestone and andesite detritus. Above is limestone and calcareous sandy shale. Shales comprise the remainder	? 500′	These rocks are strongly disturbed, commonly lenticular, and have been grouped with the Bell's Creek Volcanics. Calcareous bands with sandy shale are common. Shaly lithologies are interlayered with fine-grained siliceous rocks of the Bell's Creek Volcanics		
	Sofala Volcanics	7000′+	The type section for this formation is east of the Wiagdon Thrust. Lower part contains fine-grained dark sediments. Low-grade altered tuffs and andesitic breccias are sporadically present in the lower part, but are abundant in the upper part, where coarse-grained mafic intrusives are common	? 800′	This formation occurs east of the Wiagdon Thrust and within the thrust zone. Tuffs, andesitic breccias and coarse-grained intrusives with mafic and ultramafic mineralogy are developed		

that contain various amphibole-rich assemblages. All these rocks with a general north-south trend, are essentially intercalated and the thickness exposed is about 800 feet. Local zones of strong foliation and kink folding, particularly along the western boundary, indicate the position of the Wiagdon Thrust against psammo-pelitic schists and foliated acid rocks of the Bells Creek Volcanics. The eastern boundary may also be faulted against massive pelitic material but the lack of foliation or deformation in the latter perhaps suggests an unconformable relationship.

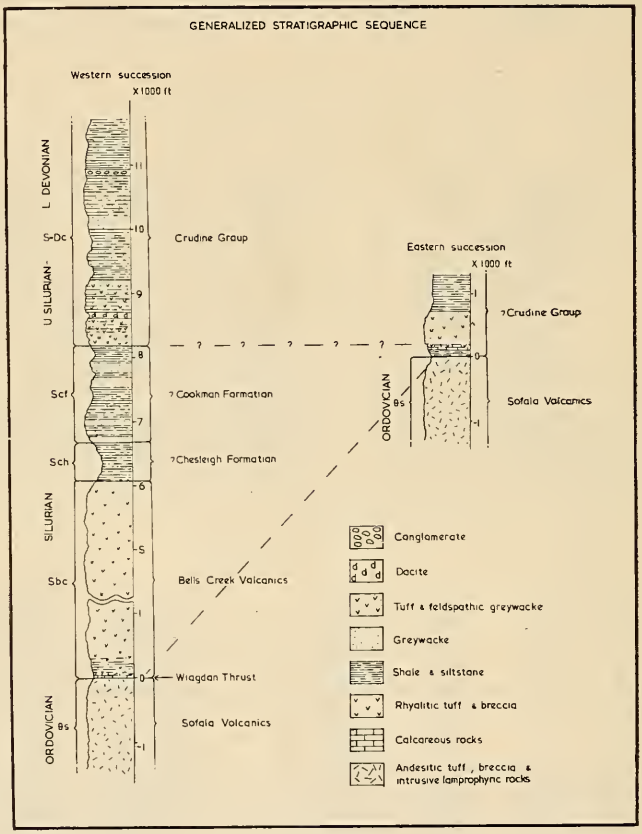


Fig. 2.

The following rock types are, in general, those most characteristic of this unit at Yetholme. A more detailed petrological and chemical study is currently in progress.

Fine grained dark green rocks which retain traces of original igneous textures and mineralogy probably represent volcanic products including flows, fine grained tuff and breccia. Fragmental rocks as a rule can be distinguished in the field, the angular fragments ranging from approximately 2 cm. to 5 cm. across. At GR 785593 they are flattened parallel to the locally developed foliation. Mineral assemblages have essentially adjusted to the hornblende hornfels facies metamorphism except where relict clinopyroxene grains rimmed with amphibole remain in the lithic fragmental material. This pyroxene is zoned and/or twinned, and relict glomeroporphyritic structures have been observed. Pseudomorphous metamorphic amphibole has, in some cases,

preserved the characteristic euhedral to subhedral pyroxene grain shapes. However such assemblages as tremolite-olivine (-spinel-phlogopite) are commonly developed and subradiating to decussate amphibole laths form the main textural feature with ragged olivine poikiloblasts developed in an elongate fashion parallel to the foliation. Green spinel granules, where present, are most abundantly associated with the olivine. In the matrix of many breccias (e.g. 33831) relict pyroxene is characteristically lacking and large (up to 1·5 mm.) densely poikiloblastic olivine grains have developed with tremolite, spinel and minor plagioclase. Such mineral assemblages are also characteristic of rocks containing no apparent textural relics.

Coarse grained metamorphosed mafic rocks with blastophenocrysts (up to 4 mm.) of amphibole and/or relict clinopyroxene suggesting a parent of perhaps lamprophyric character (cf. Basnett, 1942 and Colditz, 1948) are found both massive and brecciated. The euhedral to subhedral blastophenocrysts are easily distinguished in hand specimen as comprising up to 70% of some rocks. Traces of possible primary brecciation are suggested by angular fragments up to about 4 cm. across, in a matrix with similar textural and mineralogical features to that of the fragmental material. The relict pyroxene is commonly zoned and glomeroporphyritic as in the finer grained rock types. Zoning is marked by various concentrations of finely divided brown opaque granules. However a pale green pyroxene remarkably clear of inclusions is also present mainly as single euhedral to subhedral crystals. Both pyroxene types are considerably altered to amphibole (probably actinolite) peripherally and along cracks and cleavages. Most original phenocryst sites are, however, now occupied by pale green to colourless amphibole similar to that produced by contact metamorphism in the matrix material.

Relict plagioclase occurs only in 33840 as glomeroporphyritic aggregates and single laths containing inclusions of radiating actinolite. The blastoporphyritic texture and the mineralogy of this rock suggest that it originally may have been andesitic. However no relict groundmass minerals remain. Instead one finds generally a mat of decussate amphibole laths.

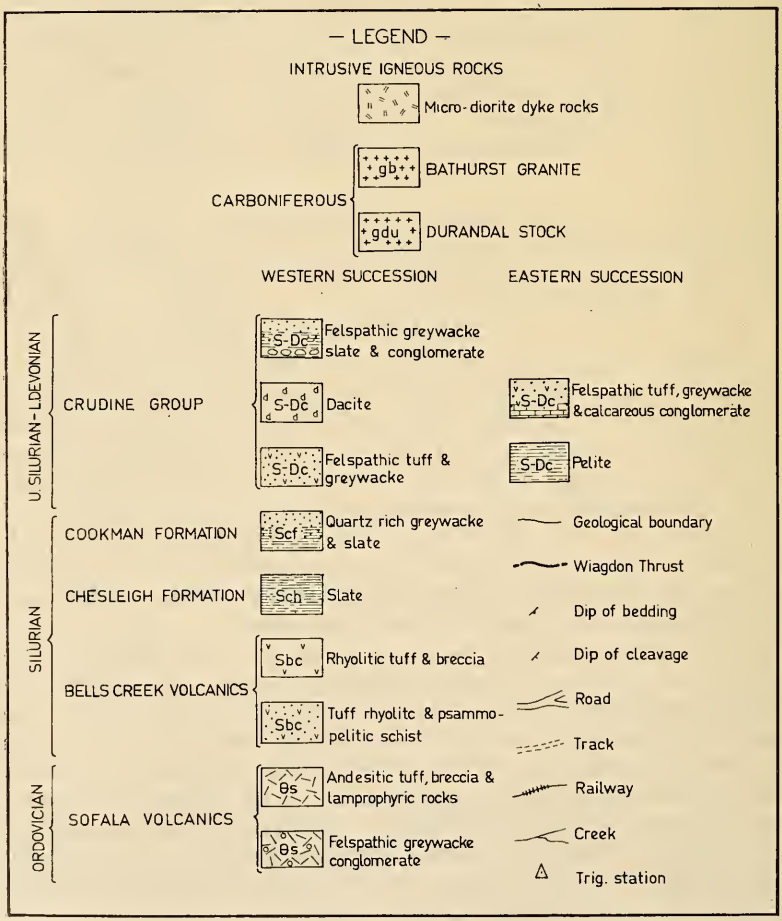
Rocks which now contain cordierite and anthophyllite are included within these volcanics. However they only retain textures related to foliation and kink folding. This is especially so in coarser grained types where amphibole needles are mimetic to a previous foliation. More commonly, however, the amphibole is subradiating to decussate. Cordierite, anthophyllite and quartz is the most widely developed assemblage (together with occasional minor biotite). Coarse grained clinochlore-anthophyllite-spinel rocks lacking all textural signs of original character have been observed and cummingtonite-bearing assemblages are also represented. Detailed work on the nature and significance of these Mg-rich rocks is in progress.

Minor calc-silicate rocks consisting of garnet, diopside, plagioclase and wollastonite are associated with these mafic and ultramafic rocks. At GR 770602 a small body containing the manganese-rich silicates rhodonite, bustamite, tephroite and garnet may form the continuation of a wollastonite-diopside-garnet bearing band at the eastern margin of these volcanics.

An occurrence of foliated conglomerate at GR 780588 is included within this unit because of its close association with these mafic rocks and limited exposure (Plate IX). This conglomerate has a matrix of detrital plagioclase laths apparently of volcanic origin. Fine grained siliceous and calc-silicate pebbles (10 mm. to approx. 30 mm. across) are now oval shaped in section and flattened parallel to the foliation.

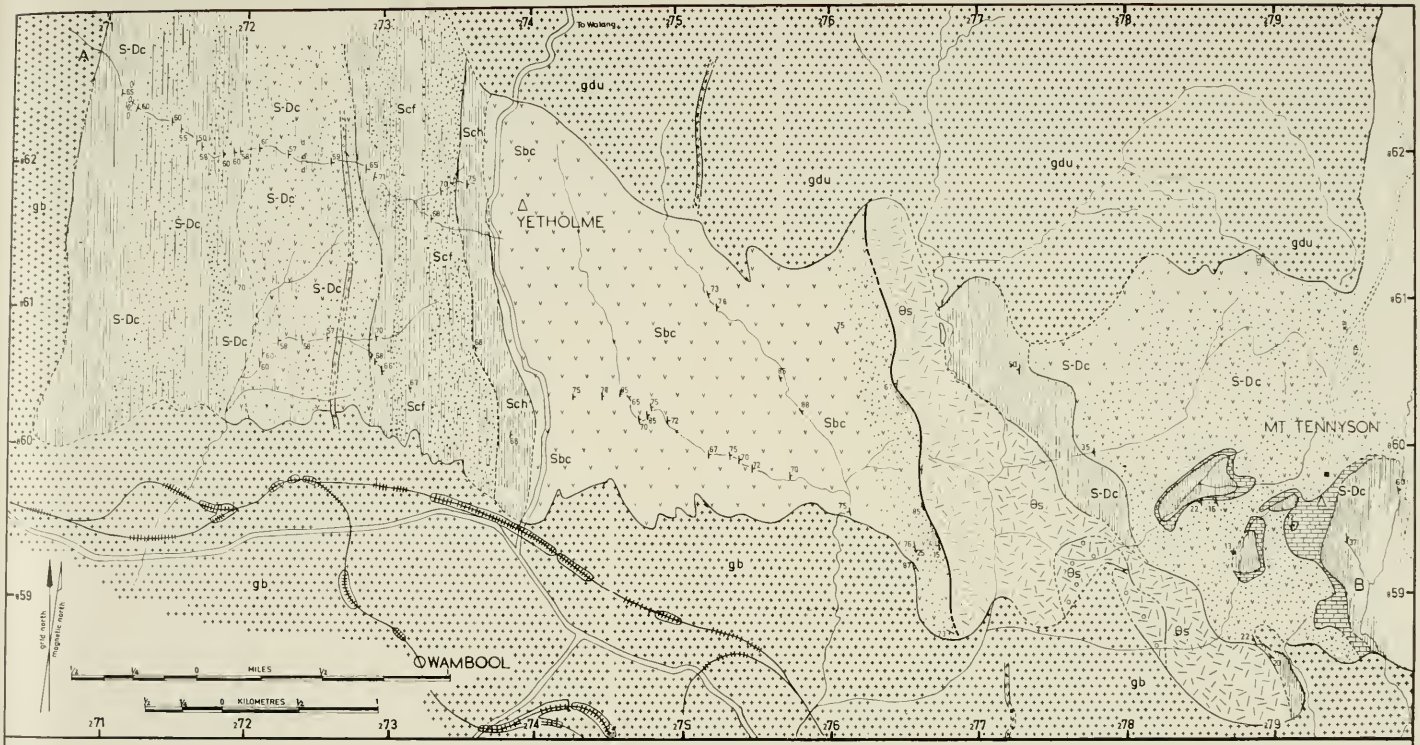
Distribution of the main rock types.—The abundant coarse grained rocks bearing numerous large amphibole and pyroxene blastophenocrysts appear to be intercalated with the finer grained lithologies. There is a tendency, however, toward concentration of finer grained rocks along the western boundary of the Sofala Volcanics and to the south-east, adjacent to the main Bathurst Granite. Cordierite-anthophyllite rocks occur in a narrow band along the Wiagdon Thrust from the northern granite contact to the south and a small exposure of this rock type is also found at GR 772600. It is important to note that cordierite-anthophyllite rocks occur to the south of the Bathurst Granite in the area described by Page (1966) and also to the north of the Durandal Stock. These occurrences lie directly along strike with the band of cordierite-anthophyllite rocks west of Mt. Tennyson. Strongly foliated lenses of the calc-silicate lithologies apparently associated with the rocks of igneous origin are concentrated along both eastern and western margins.

Regional correlation.—The distinctive petrographic character of the coarser grained amphibole and pyroxene-rich igneous rocks can be recognized north of Walang (Hobbs, 1958) and further to the north at Sofala (Packham,



Legend to Plate IX.

GEOLOGY OF THE MT. TENNYSON AREA SOUTH OF YETHOLME



1958). Considerable low grade mineralogical reconstitution within these rocks has produced chlorite, quartz, albite, carbonate, epidote and actinolite and more rarely prehnite- and pumpellyite-bearing assemblages.

As in the Yetholme breccias, strongly porphyritic fragments are common in the Sofala Volcanics at Sofala. The majority of the phenocrysts here are similarly pale green clinopyroxene and the plagioclase present is generally extensively altered to carbonates with white mica and chlorite. The vesicles developed in these porphyritic fragments contain chlorite-albite assemblages, occasionally with epidote and calcite and the matrix material consists of crystal and lithic tuff containing pyroxene, amphibole and smaller rock fragments together with the patchy alteration minerals calcite, prehnite, chlorite, quartz, albite and rarely pumpellyite.

Extensively altered fine grained tuffs or flow rocks at Sofala generally contain mafic to ultramafic low grade alteration associations including chlorite, amphibole, sphene, quartz and carbonate. Such low grade alteration, particularly along the Wiagdon Thrust has presumably taken place prior to essentially isochemical thermal metamorphism of the Yetholme rocks.

In the lower part of the Sofala Volcanics of the type section to the east of Sofala, abundant dark grey to black fine grained (commonly brecciated) sediments occur together with lithologies containing andesitic and sedimentary cobbles in a fine grained sedimentary matrix. In this part of the succession sedimentary structures and upper Ordovician fossils are suggested by Packham (1958) to represent a deep water environment. South of the Bathurst Granite, Page (1966; Fig. 1) has identified fine grained dark pelitic lithologies associated with mafic rocks similar in mineralogy and texture to those at Yetholme. However fine grained pelitic lithologies are not characteristic of the latter. The upper part of the Sofala succession contains breccias mainly with angular blocks of andesitic material and abundant minor intrusions of lamprophyric rock types. Limestone blocks have also been noted at Sofala by Packham (1958), who suggested their presence may be related to shallowing by orogenic movement.

Thus the sequence characteristic of the middle and upper part of the type section is perhaps represented in the Sofala Volcanics at Yetholme and if they are also time equivalent then an upper Ordivician to lower Silurian age may be indicated.

Bell's Creek Volcanics

The Bell's Creek Volcanics occur west of the Sofala Volcanics and consist of a rather monotonous, strongly foliated succession of rocks with extremely felsic mineralogy. Relatively fine grained strongly deformed rocks with a characteristic lenticular layering are common. All textures indicating the nature of original rock type have generally been obliterated by deformation, and recrystallization effects imposed during contact metamorphism. However a few weakly foliated rocks contain relict textures that suggest former acid volcanic character. Minor rocks of pelitic and psammo-pelitic composition are strongly foliated and retain no original textural features. Any estimation of true thickness of this unit (Fig. 2) is probably invalidated by repeated faulting. The eastern boundary of these rocks against the mafic Sofala Volcanics is the Wiagdon Thrust, and the western boundary, against strongly foliated pelitic rocks, may also be faulted. However kink folding is not apparent along the latter. The most characteristic rock types of the Bell's Creek Volcanics south-west of Yetholme are described below.

Fine grained lenticular foliated rocks which probably represent acid volcanics contain sparsely distributed small blastophenocrysts of quartz and plagioclase. The quartz is commonly euhedral and rarely retains textures of resorption. Glomeroporphyritic textures can be recognized in some small plagioclase aggregates. However no former textures remain in the surrounding material which is fine grained and felsitic, consisting mainly of quartz and plagioclase with minor microcline and biotite. The latter has developed parallel to the previous foliation. Unfoliated fine grained rocks are generally more leucocratic than biotite-bearing types and contain little suggestion of original porphyritic character. Patches with slightly coarser grainsize show the same textural relations as the surrounding granoblastic material.

Brecciated examples are represented within the layered acid rocks that comprise the main part of this unit. However brecciation is often difficult to recognize when the fragments have been rendered completely lenticular within a petrographically identical matrix. Biotite tends to occur with the granoblastic quartz and felspar of the surrounding medium rather than within the fragmental material, which is slightly more siliceous. Strongly brecciated rocks at GR 766588 contain typically augen-shaped siliceous fragments (approximately 6 cm. max. direction) that are mineralogically similar to the matrix. The proximity of this example to the strongly deformed fault zone may indicate tectonic derivation rather than original pyroclastic vulcanism.

Large plagioclase blastophenocrysts up to 3 mm. in length are rarely evident in some fragments and commonly glomeroporphyritic structure has been observed. Smaller "microlites" of former plagioclase in more or less random orientation are apparent only in plane polarized light where recrystallized elongate granular aggregates are now similar to the micro-hornfelsic enclosing medium.

The light brown to buff mica schists composed mainly of quartz, muscovite and biotite with minor plagioclase may also contain cordierite. The textural features of these rocks largely depend on the impressed structural elements and the foliation is further deformed by a strain-slip cleavage in examples such as 33890. Psammo-pelitic schists concentrated within the fault zone contain a considerable amount of quartz and commonly cordierite is lacking.

Calc-silicate rocks, which bear no original textures, are mainly lenticular and mineral assemblages are essentially similar to those in other formations. However a vesuvianite-garnet-plagioclase-quartz association is developed at GR 742597.

Distribution of the main rock types.—The pelitic lithologies with minor lenses of calc-silicate rock are strongly foliated and concentrated along the Wiagdon Thrust at the eastern boundary of this unit. These rocks, particularly the fine grained foliated rocks, are abundant for about 600 to 800 feet upwards into the lighter coloured quartz rich banded acid volcanics and thin pelitic layers are sporadically intercalated with the volcanics in this part of the unit. Several small discontinuous lenses of brecciated rocks also occur in this eastern part of the succession and massive fine grained quartz rich hornfelses outcrop in almost cliff forming exposures (at GR 753605) above these relatively thin brecciated examples.

Lenticular, layered rocks comprise the major part of the sequence and are developed above the thin pelitic bands which decline in abundance westwards from the thrust zone.

Regional correlation.—The petrographically similar fine grained acid volcanic rocks mapped by Hobbs (1958) above mafic volcanic and intrusive rocks north of Walang, are considerably outside any thermal effects imposed

by the Bathurst Granite. Textures indicate the main rock type to be an acid tuff consisting of fine grained quartz and felspar in which are set small, often euhedral crystals of quartz. These rocks are massive in outcrop and strongly jointed; thus cleavage development associated with faulting probably initiated the lenticular and finely banded nature of the rock types comprising the main part of the unit at Yetholme.

In the Sofala-Turondale area (Packham, 1951, 1958) the Tanwarra Shale is interbedded with the Sofala Volcanics at its base and the Bell's Creek Volcanics at the top. It consists of calcareous shale with siliceous shale and minor lenses of limestone and is substantially foliated in the vicinity of Sofala. Graptolites indicate a Silurian age for the Tanwarra Shale (Packham, 1958). The overlying Bell's Creek Volcanics west of Sofala consists of fine grained acid tuffs and lavas rich in quartz, orthoclase and dark biotite.

The rocks within the thrust zone at the base of the quartzo-felspathic unit at Yetholme may thus be the Silurian Tanwarra Shale assuming that petrological and stratigraphic similarity is a valid basis for correlation.

Some parts of the Sofala-Turondale succession defined by Packham are apparently not represented to the south in the contact metamorphosed succession at Yetholme where primary sedimentary features become extremely difficult to recognize. However direct correlation with lower grade units north of Yetholme (Hobbs, 1958; Mackay, 1962) is possible for a small part of the sequence.

? Chesleigh Formation

This formation at Yetholme is thought to be represented by a massive pelitic lithology that appears to bear faulted relations with adjacent beds. The thickness exposed is about 600 feet and no intercalation with neighbouring units is evident. These fine grained buff coloured slates consist only of quartz and micas with occasional porphyroblasts that have largely retrogressed to micas. Cordierite is only locally developed. A lenticular compositional layering parallel to the original foliation is composed of quartz rich layers alternating with mica rich layers. This layering is gently deflected around the large pseudomorphed porphyroblasts that may represent former andalusite crystals. Two small calc-silicate lenses exposed towards the northern extremity of this unit (at GR 738623) consist of wollastonite-garnet-diopside assemblages with epidote and plagioclase.

This part of the succession may doubtfully be correlated with the lower part of the Chesleigh Formation in the Sofala stratigraphy. The upper part of the Chesleigh Formation as represented west of Sofala appears to be absent at Yetholme.

? Cookman Formation

Interbedded coarse and fine grained greywackes, together with slates, are exposed for approximately 1,500 feet of the succession above the fine grained foliated rocks perhaps belonging to the Chesleigh Formation. The boundary with the latter unit is easily defined as the lowest, 60 feet thick bed of quartz-rich greywacke and the top of this unit is the boundary of a thick slate band with the first occurrence of a massive felspathic tuff of the overlying Crudine Group. Three main rock types characterize this unit.

A poorly sorted rock containing angular detrital grains (about 0·5 mm. across) that have a more or less even distribution throughout the matrix, has been moderately affected by the regional cleavage. Of the detritus quartz and felspar are approximately equally developed. The felspar, dominantly

sodic andesine, is extremely clouded (e.g. 33924). The matrix which consists mainly of fine grained quartz and micas is not tectonically differentiated into layers of different mineralogical composition as are the finer grained shaly lithologies of this unit. Graded bedding, commonly developed on a small scale within these relatively fine grained quartz rich ricks involves only small differences in grainsize and indicates that the beds are in fact, overturned. Dip of bedding is approximately 70° towards the east and is essentially parallel to the slaty cleavage. These sediments probably belong to a deep water suite (Packham, 1954) and may be classified as sublabile greywackes.

A considerably coarser grained labile greywacke contains detritus from 0·5 mm. to 1·5 mm. across, and the degree of sorting is higher than for that described above. The matrix, which only constitutes about 30% of the rock, contains a small amount of micaceous material with recrystallized quartz and felspar and small laths of bluish-green metamorphic hornblende. The detritus is similar to that described above. However, fairly angular clear quartz grains about 1·5 mm. across are rather distinctive in hand specimen.

The fine grained slates interbedded with the above lithologies are similar to those developed in the Chesleigh Formation below.

Distribution of the main rock types.—The three main lithologies throughout this unit are interbedded (Fig. 2) on the scale of 60 to 80 feet, with some beds consisting of alternating fine grained quartz rich greywacke and slate several inches to a foot thick. The detritus of coarser grained members becomes slightly more felspathic towards the top of this formation, where slaty lithologies are more prominent.

Regional correlation.—The upper part of this formation can be directly correlated with the southern part of the area mapped by Hobbs (1958) and Williams (1961), where it consists of fine grained quartz rich greywacke regularly interbedded with black shale. Graded bedding is common in parts of the formation together with slumping and flow casts. These features are also present west of Sofala (Packham, 1958) where this formation consists dominantly of slate with interbedded fine to medium grained quartz-rich subgreywacke and sublabile greywacke. Here a thick shale band defines the top of this formation against the overlying coarse grained tuffaceous rocks of the Crudine Group, as at Yetholme. Lithological similarity together with a somewhat similar distribution of rock types is considered sufficient reason to correlate Yetholme rocks with the Cookman Formation west of Sofala.

Crudine Group

This group at Yetholme is marked by the development of massive felspathic tuff directly above the thick upper slate band of the Cookman Formation. The upper part of this group at Yetholme is characterized by a paucity of tuffaceous rocks, slates becoming more abundant than coarser grained rocks. One thin conglomerate horizon is present towards the top of the 1,800 feet of sequence exposed. The top of this unit is not represented as it is truncated by granite. Outcrop is generally poor in the vicinity of GR 712626 where numerous thin tongues of granite and quartz have been intruded parallel to the regional foliation. The following rock types are present within this group.

Coarse grained felspathic rocks in which the average grainsize is about 1·2 mm. are taken to represent felspathic greywackes and tuffs. The detritus is chiefly volcanic and abundant relict plagioclase (An_{30-35}) is lath shaped

and more rarely glomeroporphyritic. Small granules of epidote are contained in some clouded plagioclase laths. Perthitic alkali felspar is less common and fairly large embayed quartz grains up to 2 mm. form less than 5% of the detritus. It is difficult to estimate the percentage of matrix compared with detritus in some of these rocks, since bluish-green, subradiating aggregates of metamorphic amphibole are abundant and commonly project into the felspar grains obscuring former textures.

Blastoporphyritic rocks containing coarse relict plagioclase laths and occasional rounded and embayed grains of quartz in a fine grained "groundmass" of recrystallized plagioclase and quartz perhaps represent dacitic flows. The plagioclase is present as both single crystals and glomeroporphyritic aggregates and two size ranges are apparent: large grains from 3 mm. to 5 mm. and abundant smaller laths from 0·5 mm. to 1·5 mm. Any evidence of flow or vesiculation has been obliterated by recrystallization and formation of biotite, hornblende and minor epidote. The development of microcline is commonly limited to the recrystallized groundmass material.

Fine grained greyish slates commonly containing cordierite and biotite represent interbedded pelitic lithologies within this dominantly volcanic unit. The properties of these rocks are similar to those of the slates in the ? Chesleigh Formation.

A coarse cobble conglomerate at GR 712624 consists mainly of severely flattened but well rounded quartzite cobbles up to 5 inches across (long dimension) and smaller biotite-muscovite schist pebbles (about 2·5–1 inch, maximum dimension) set in a fine grained schistose matrix containing cordierite, biotite, muscovite and quartz. This assemblage is typical of the fine grained pelitic lithologies near the western contact with the Bathurst Granite.

Distribution of the main rock types.—The felspathic tuffs and/or greywackes are the most common rock types developed. About 800 feet of these massive rocks occur basally but give way to small thicknesses of interbedded fine grained slaty material higher in the succession. About 80 feet of porphyritic dacitic rocks overlie the "tuffs". These are overlain by 400 feet of felspathic tuffaceous greywacke with thin beds of knotted slate. Above this about 800 feet of massive slate is present with thin bands of interbedded felspathic tuffaceous or greywacke sediments developed in the central 200 feet of the main pelitic lithology. Inverted graded bedding in the fine grained pelites dips at approximately 60° to the east.

Massive, strongly foliated and in some cases mesoscopically folded rocks comprise the remainder of this unit and the growth of contact metamorphic minerals precludes the identification of previous textural elements. The thin band of coarse cobble conglomerate occurs close to the western granite contact within the dominant pelitic lithology.

Regional correlation.—The type section of the Crudine Group near Turondale (Packham, 1958, 1968) is similar to the succession of volcanic derivatives and flows west of Yetholme. The lowest part of the formation is composed almost entirely of tuffaceous material with relatively scarce slate and fine grained sandstones. The basal conglomerate present at Turondale is absent at Yetholme. However, the overlying tuffaceous rocks consisting of quartz, felspar, chlorite and epidote are petrologically similar to the Yetholme rocks. They are hard and massive and graded bedding is common. Interbedded fine grained greywackes and slates are developed above the tuffaceous sediments. These are followed by more massive tuffaceous rocks and then dominantly slate and silt with minor greywacke for the rest of the unit.

The upper part of the lower formation (the Turondale Formation) of the Crudine Group south of the type section, however, contains conglomerates up to several hundred feet thick. The pebbles are mainly quartzite, quartz porphyry, limestone and shaly rocks. The quartzite pebbles range from "less than an inch to six to eight inches along their greatest dimension" (Packham, 1968). The conglomerate band west of Yetholme, although fairly thin, and developed close to the granite contact, is similar in most respects to that developed south of the type section at Turondale, and probably represents an important marker horizon for the correlation of this unit with the upper part of the Turondale Formation of the Crudine Group in the Sofala-Turondale stratigraphy.

Thus it appears that most of the Turondale Formation of the lower Crudine Group is represented in the Yetholme succession 30 miles to the south of the type section.

The Eastern Succession

Only three units occur to the east of the Wiagdon Thrust in the area under discussion. These rocks may be equivalent to the Crudine Group of the western succession. However such correlation at Yetholme could only be of a most general nature based on lithological similarity. The regional geology of the eastern succession is not entirely clear in this vicinity as compared with the Limekilns stratigraphy of Packham (1968).

? Crudine Group

At Yetholme coarse grained tuffaceous rocks together with greywackes and fine sediments are more massive than those belonging to the western sequence. Sedimentary structures are generally lacking and individual beds are difficult to distinguish. However a fine layering which may be interpreted as bedding is well-developed in the pelitic lithologies. An extensive molybdenite-bearing skarn horizon occurs at the base of the greywacke and tuffaceous rocks and appears to be a former calcareous conglomerate horizon. The mineralogy and chemistry of these rocks are present subjects of investigation. Cleavage is characteristically absent from this succession which shows gentle concentric folding.

About 40 feet of a banded pelitic lithology is exposed basally and the individual sub-parallel bands are about 1 cm. to 0·5 cm. thick. Alternating quartz-rich and cordierite-rich units define this layering in rocks now consisting mainly of cordierite, biotite and quartz. Although this metamorphic assemblage is typical of a pelite, much material may be fine grained tuff (Mackay, 1961).

The sudden appearance of a calcareous cobble conglomerate marks the base of the following 600 feet of massive tuffs and greywackes. The thickness of the conglomerate varies considerably from about 5 feet to about 40 feet and in the basal section consists mainly of a wollastonite-bearing rock with garnet, diopside and quartz. The wollastonite occurs in subrounded patches, commonly 3 to 6 cm. across and rarely up to 3 feet across. These perhaps represent former pebbles and cobbles between which diopside-garnet assemblages are developed. Wollastonite is absent from the overlying conglomerate and garnet-quartz-calcite-diopside is the main association represented. The pebbles and cobbles in this upper part are strongly zoned and commonly retain volcanic textures; quartz rich inclusions and pelitic lithologies are also represented. Molybdenite mineralization is associated

with this upper conglomerate and is localized mainly within the garnet-quartz-calcite-diopside skarn.

In the greywackes and tuffs above the basal conglomerate quartz and felspar constitute most of the detrital material. The average grainsize is between 0·5 mm. and 1·5 mm. and is consistent throughout the lateral and stratigraphic extent of this lithology. The quartz grains are extremely angular to euhedral and many are deeply embayed (e.g. 33992). The euhedral crystals commonly show double terminations, fracturing and displacement. The plagioclase detritus is clouded and angular; however some plagioclase is distinctly subhedral to euhedral. Of the detrital material the proportion of quartz to labile components is as high as 70 : 30 in some rocks. However rocks containing only plagioclase detritus are also abundant.

The matrix material consists of fine-grained granoblastic quartz and felspar, rarely with cordierite, and constitutes approximately 30% of most rocks. In slightly more calcareous lithologies the finer grained fraction includes metamorphic diopside but the coarse-grained fraction is similar to that described above.

Well-rounded acid volcanic and pelitic pebbles which occur in these tuffaceous arenites at GR 781592 vary in size from about 4 cm. to 1 cm. across and generally consist of a microfelsite with relict textures suggesting an acid volcanic source.

The upper limit of these coarse-grained rocks is well defined against a pelitic lithology mineralogically similar to that developed below. Only 600 feet of this lithology is exposed and its western boundary against the mafic rocks of the Sofala Volcanics is faulted or perhaps represents an unconformity. This unit is more extensively exposed to the east (Mackay, 1964; Goldner, 1966) where two distinct conglomerate members break a monotonous series of shales with rare fine quartz-rich tuffaceous rocks. A conglomerate band about 20 feet thick occurs at GR 790586 on the western side of Mt. Tennyson where it consists of small (1 cm. to 3 cm.) well rounded pebbles set in a matrix of banded pelitic material. Fine grained quartz-rich pebbles are most abundant together with pebbles containing granoblastic quartz-plagioclase-biotite assemblages and pelitic lithologies now represented by purplish cordierite-biotite rocks.

Small calc-silicate lenses at the western boundary of this unit with the Sofala Volcanics contain wollastonite-garnet-diopside assemblages. The manganese-bearing rocks previously mentioned may actually be associated with the rocks of this unit rather than with the mafic rocks of the Sofala Volcanics. This situation is unclear, however, due to poor outcrop.

Intrusive Rocks

The Durandal Stock

An essentially equidimensional body, named by Mackay (1964) after the property Durandal, this stock consists of the following three lithologies: a leucocratic granite with only sparsely developed potash felspar "megacrysts", a "megacrystalline" granite and a fine grained marginal phase. The non-genetic term "megacryst" was adopted by Mackay (1964) and "normal" granite was defined as containing less than 1% megacrysts. The latter generally occurs toward the central part of the stock.

The fine grained marginal granite consists mainly of an equigranular (i.e. about 0·5 mm.) quartz, plagioclase and potash felspar aggregate. The potash felspar in most cases is finely perthitic and the plagioclase is strongly

zoned. A few elongate subhedral biotite grains are commonly altered to chlorite, and minor apatite is enclosed by or associated with the biotite. Myrmekitic intergrowths are common and fan-like projections locally extend into adjacent potash felspar grains. Quartz phenocrysts (up to 2 mm.) are rarely present. These are anhedral against the enclosing finer grained material as described above. Plagioclase phenocrysts are of a similar size and also anhedral. Modally, quartz forms about 40% and the percentage of potassic felspar and plagioclase is similar, indicating that these rocks are micro-adamellites. The modal mineral composition of this rock type appears to be extremely constant.

Megacrystalline granite contains megacrysts up to 6 cm. but usually 3 cm. to 4 cm. long. These are strongly perthitic orthoclase, containing small, irregular biotite flakes, quartz and plagioclase. Intricately sutured margins enclose quartz and felspar blebs. Myrmekitic intergrowths are also common at the boundaries of such grains. The granite between the megacrysts is usually quite granular. However in some examples it may be porphyritic in quartz and plagioclase. Large (up to 6 mm.), slightly embayed quartz grains and smaller (about 4 mm.) zoned plagioclase phenocrysts (about An_{27} centrally) which are commonly glomeroporphyritic, are enclosed in a groundmass of quartz, plagioclase and potash felspar with an average grainsize of about 0·5 mm. Biotite, magnetite and sphene are accessory. The approximate modal percentages are 40% quartz, 32% plagioclase, 25% potash felspar and 3% sphene, biotite and magnetite. This granite with gradual loss of megacrysts grades imperceptibly into "normal" granite containing less than 1% megacrysts.

Small allotriomorphic granular xenoliths (up to 5 cm.) contain quartz, plagioclase, potash felspar and biotite with euhedral sphene. The plagioclase shows normal progressive and oscillatory zoning. The potash felspar is finely perthitic and the biotite is usually of similar dimensions to that of the surrounding granite. The small aplite veins and dykes, and long, narrow microdiorite dykes are similar to those in the Bathurst Granite to the south.

The Bathurst Granite

The Durandal Stock is narrowly separated from the main Bathurst Granite which outcrops over 500 square miles and extends from Hartley to Newbridge. Upper Devonian rocks are the youngest intruded by the Bathurst Granite (Mackay, 1964; Goldner, 1966) and the age of part of the granite (near Hartley) has been dated as Middle Carboniferous (Evernden and Richards, 1962).

In the area to the south of Yetholme all the stratified rocks are intruded by the Bathurst Granite, the overall contact relationships being strongly transgressive. However, to the west of the Wiagdon Thrust the contact assumes a sheeted character with narrow tongues of granite parallel to the well-developed regional foliation. To the east, broad curving tongues of granite preferentially intrude selected lithologies.

The granite at Yetholme appears to be particularly uniform. It is porphyritic, but only in one locality (739595) does megacrystalline granite, in the sense of Mackay, occur. A fine grained marginal phase of similar petrographic character to that of the Durandal Stock locally intrudes the foliated rocks in a sheeted manner and is also sporadically developed along the eastern contact.

Biotite (-hornblende) adamellite is most widely developed with a grain-size of approximately 4 mm. and allotriomorphic granular texture. Modally

this consists of about 30% quartz, 35% potassic felspar and 30% plagioclase with 5% biotite. The potassic felspar is finely perthitic orthoclase with lesser microcline. Minor intergrowths of quartz mark grain boundaries of potassic felspar against plagioclase. The latter shows strong normal progressive zoning and occurs as subhedral somewhat irregular laths. Large grains of muscovite and chloritized biotite are common accessories together with euhedral sphene and apatite.

Aplite dykes are commonly joint controlled (e.g. GR 588765). The aplite consists of granular quartz, plagioclase and potash felspar with biotite practically absent. The grainsize is fairly constant from about 0·1 mm. to 0·5 mm. and the approximate modal composition is quartz 40%, plagioclase 25% and potash felspar 35%. The potash felspar is again finely perthitic (33887) and rarely myrmekite is present at grain boundaries. Apatite is euhedral and associated with the sparse biotite grains.

A small occurrence of micrographic pegmatite occurs at GR 780591. The quartz "runes" are embedded in microcline and also appear to extend into the small plagioclase laths adjacent to the microcline.

Two types of inclusion are present in this granite. Well rounded granitic xenoliths up to 5 feet across but more commonly 3 to 6 inches, contain noticeably more biotite than the surrounding granite and are finer grained with strongly zoned plagioclase. The quartz grains are irregular, and potash felspar constitutes considerably less of the felspar fraction than plagioclase. Biotite constitutes up to 10% of some inclusions and occurs in subradiating and decussate aggregates commonly 3 cm. across (33850). Apatite is a constant accessory in these inclusions.

At GR 726599 in a small granite quarry, rafts of strongly metamorphosed foliated rocks up to 40 feet (maximum direction) are enclosed by the granite. These are horizontally elongate and only one rock type appears to be present. This is now a biotite-plagioclase-hornblende-quartz-microcline rock in which the biotite accentuates an original foliation and hornblende forms subradiating clusters. It is not possible to indicate the formation from which these xenoliths were derived.

Basic dykes

Long narrow basic dykes have been intruded parallel to the north-south regional trend of the country rocks and in some cases can be traced into the granite. A characteristic outcrop of small rounded boulders can be followed for distances probably exceeding one mile. They are about 20 feet to 50 feet across. Such dykes intrude both the Durandal Stock and the Bathurst Granite.

All the dyke rocks are extremely similar with an intergranular texture and average grainsize of about 0·5 mm. Plagioclase is glomeroporphyritic and is mainly An_{30}. However in most cases it is altered to patchy calcite and sericite with minor epidote. A few large anhedral to subhedral phenocrysts of augite are present. The elongate plagioclase laths of the groundmass, comprising about 40% of the rock, are interspersed with laths of brown amphibole. A small number of interstitial quartz grains are also present. The common accessories of these microdioritic dyke rocks include small euhedral sphene granules, apatite and peppery magnetite euhedra. In some rocks rounded patches of calcite up to 5 mm. across are present and probably fill amygdales. These rocks have thus undergone considerable low grade adjustment. Deuteric alteration or adjustment due to burial at depth are possible causes.

Structure

The structural basis for the division of the stratigraphy into two separate successions reflects the strongly developed tectonic elements west of the Wiagdon Thrust, compared with the gently folded massive rocks of the eastern succession. Similarly a discussion of the structure will also be divided into two sections.

The Western Succession

The western structural block of the area mapped by Hobbs (1958; Fig. 1) is the northern continuation of sediments occurring to the west of the Wiagdon Thrust at Yetholme and structural features of the sediments are essentially similar.

The most prominent s-surface developed is a slaty cleavage, characteristic of the finer grained lithologies, and is closely parallel to the few observed examples of true bedding. This regional cleavage has a strike of about 340° and the dip is constantly east at reasonably high angles, i.e. about 70°. However the regional cleavage fans near the Wiagdon Thrust first becoming vertical then dipping at high angles towards the west. Although the slaty cleavage pre-dates thermal effects, extensive recrystallization, especially of biotite, has emphasized the earlier textures.

There is no evidence in this area as to whether the development of this cleavage accompanied folding of a primary lithological layering. On a regional scale, the fan-like attitude of the foliation may be axial plane to a much larger folded structure, the scale of which does not allow interpretation within the mapped area. Such intense cleavage development is commonly related to reasonably appressed folding (Turner and Weiss, 1963).

A strain-slip cleavage is only developed locally within the fine grained lithologies and consists of alternating mica-rich and quartz-rich bands. Large flakes of contact metamorphic white mica have developed, accentuating this cleavage. At GR 766588 the strain-slip cleavage is well developed, deforming the slaty cleavage and cutting the latter at a reasonably high angle. (The strain-slip cleavage dips at 75° to 125°; the slaty cleavage dips at 85° to 245°.) In other localities the development of strain-slip cleavage is gradational to rocks exhibiting only slaty cleavage. In most rocks strain-slip cleavage is completely absent.

The most conspicuous layering observed in the area is of unrecognizable stratigraphic significance and is probably of metamorphic origin. It may represent a transposed lamination. Flat lenses, which vary considerably in size and thickness are characteristic of the Bells Creek Volcanics. Generally they are in the order of about 20 cm. long and from 1 mm. to about 3 cm. in width. In the lenticular quartz-rich material foliation is generally not obviously developed mesoscopically. The layering developed within fine pelitic lithologies is a finer differentiation lamination and in a few rocks isolated hinges of folds can be discerned on a small scale. Lenticles flattened in the plane of the slaty cleavage are finally produced.

True bedding especially in fine grained lithologies is thus not easily recognized in these foliated rocks. Bedding was probably never present within the Bell's Creek Volcanics. However in medium grained rocks, beds vary from about two feet to a few inches thick. At GR 719620 the intersection of bedding with slaty cleavage indicates that the beds are overturned. Graded bedding also suggesting that the succession is inverted is mainly developed on a small scale with many thin graded beds developed in the one unit.

A prominent lineation in the foliated acid rocks west of the Wiagdon Thrust is defined by a linear preferred orientation of biotite grains. This

lineation is essentially a mineral streaking which pitches about 75° north in the plane of the slaty cleavage. The lineation developed within the finer grained lithologies appears as a fine crenulation on slaty cleavage surfaces. It may represent the intersection of an incipient strain-slip cleavage with slaty cleavage. On a much larger scale the long axes of deformed pebbles in the conglomerate at GR 712624 also define a lineation. Another lineation defined by small crenulations is rarely developed on the surface of the quartz rich pebbles in this conglomerate.

Folding occurs most commonly in the slaty cleavage in areas of maximum deformation—that is, along the Wiagdon Thrust and at GR 718622 where kink folds with shallow plunges are developed. Within the Wiagdon Thrust small, shallowing plunging concentric folds are developed with asymmetry towards the west. To the east of these kink folding is common. Axial planes have variable orientation and fan about the fold axis.

The Eastern Succession

Bedding, the most important structural element, is gently concentrically folded into a broad anticlinal structure the subhorizontal meridional axis of which occurs on the eastern side of Mt. Tennyson. Small flexures slightly complicate the structure (Plate IX).

The effect of the intrusion of the Bathurst Granite is such that the slaty cleavage has changed its gross orientation throughout the entire area as compared with observations to the north (Hobbs, 1958). The steep westerly dip changes gradually southwards to vertical and then to 50° or 60° north-east near the granite contact (Hobbs, 1969). This change, he states, has apparently been accomplished by large scale kink folding.

Summary and Conclusions

Owing to confined outcrop of these strongly contact metamorphosed rocks between the Bathurst Granite and Durandal Stock, the stratigraphic succession is elucidated mainly by comparison of lithology, lithological distribution and structure in areas to the north.

Two sequences can be recognized—a western succession and an eastern succession separated by a narrow continuous thrust zone. Primary textural features are poorly preserved in rocks of the western succession and the well developed slaty cleavage in some finer lithologies has been further deformed by a strain-slip cleavage. In the eastern succession bedding is the main structural element and has been concentrically folded into a broad anticlinal structure. Original textural features are usually visible and the penetrative cleavage of the western succession is lacking. Some rock types are common to both divisions but it is difficult to tell whether the sequences are time-equivalent since correlation is not possible across the thrust zone. The main difference between them is thus tectonic style.

In the western sequence the oldest exposed rocks are the Ordovician to Silurian Sofala Volcanics. They are altered dark-green rocks originally perhaps of andesitic composition, now with mafic and ultramafic mineralogy. These rocks appear to include flows, pyroclasts and related porphyritic intrusive rocks. The unit has faulted relations with adjacent beds, but is thought to form a structurally high area where the thinner eastern succession of Silurian to ? Devonian calcareous sediments with acid volcanics is developed. To the west, foliated pelitic and minor calc-silicate lithologies grade into the foliated acid rocks of the Bell's Creek Volcanics. A thick succession of felsic to intermediate volcanic rocks and unfossiliferous greywacke and slate stratigraphically above the Bell's Creek Volcanics, is related